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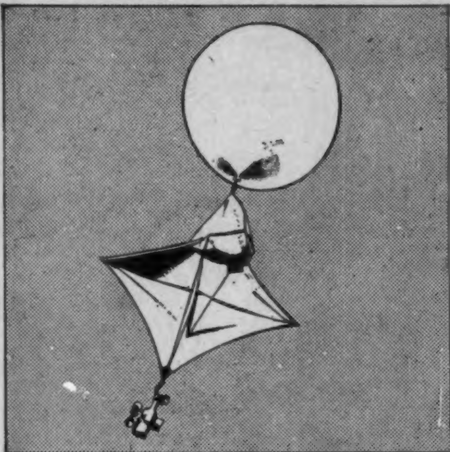

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CLOUD TOPS OVER MALAYA DURING THE SOUTH-WEST MONSOON SEASON

By R. F. ZOBEL, O.B.E. and S. G. CORNFORD

The project.—The Canberra aircraft of the Meteorological Research Flight was sent to RAF Station, Changi, Singapore, in order to obtain a general survey of the high-level cloud distribution, i.e. cirrus and cumulonimbus, in the Malaysian area during a period of south-west monsoon over south-east Asia. The survey took place during the period 8 – 21 July 1965.

In view of the unknown, but almost certainly severe, nature of turbulence inside cumulonimbus clouds in the area and the possibility of encountering cumulonimbus clouds invisibly embedded in cirrus, it was not the intention to enter cloud for the purpose of measuring vertical velocities because although the aircraft used is instrumented for such a purpose it is structurally unsuitable for use in cumulonimbus clouds and it has no forward-looking radar to assist in avoiding the precipitation cores.

Observational procedure.—Since the object was merely a survey of the highest clouds to be found on about 20 flights over a limited part of south-east Asia during part of a single south-west monsoon season, there was no point in attempting to measure cloud tops with great accuracy. Consequently estimation of cloud top height by the meteorological observer was intended to be used as the main basis of measurement.

The aircraft was however fitted with three fixed cameras which can take photographs horizontally to port and starboard, and vertically downwards. It was therefore possible from a sequence of shots at known intervals and a knowledge of the camera dimensions to calculate the height of the cloud and its distance from the aircraft.

The main difficulty in interpreting the photographs is that they frequently do not show the horizon. The position of the horizon on the photographs depends mainly on the angle of roll of the aircraft but there are also difficulties due to yawing and pitching of the aircraft as well as to inadvertent changes of course. Records of the rolling, yawing and pitching were made on the aircraft but the desired accuracy in cloud height to within 2000 feet could be expected to be realized by simple eye estimation, so that the labour involved in measuring photographs and trace recordings was not justified. A few photographs of cumulonimbus tops have however been measured and these confirm that the eye estimates were reliable. It is, of course, necessary to rely on the latter for the cirrus heights, as cirrus lacks distinctive features

of shape. All heights in this report are on the ICAO (International Civil Aviation Organization) scale. True heights prevailing were approximately 2000 ft greater. Distances between cumulonimbus clouds are entirely the observer's eye estimates.

The flights.—A total of 20 flights had been hoped for but only 9 were successfully made, all over Malaya and adjacent waters ; other flights planned were abandoned because of unserviceability of the aircraft and because it was found impossible to avoid cloud penetrations during which turbulence occurred of sufficient degree to constitute a hazard to the aircraft which was already flying near its ceiling. It is thought that some of the aircraft faults which developed were in fact caused by turbulence during inadvertent cloud penetrations.

The ceiling of the aircraft is limited to 48,000 ft for operational reasons but in the low temperature conditions prevailing, safety and all-up weight considerations led to a ceiling, in several instances, well short of this value. This meant that the aircraft often did not reach the cloud tops until late in the sortie, if at all. These limitations led to a number of unavoidable cloud penetrations. Such penetrations were never intentionally made into cloud other than cirrus. On at least one occasion however the turbulence was so violent that it seems likely that cumulonimbus clouds may have been embedded in the cirrus.

The cloud conditions.—The overall picture of the cloud conditions is one of large amounts of cirrus, mainly associated with cumulonimbus tops, but only rather infrequently penetrated by cumulonimbus.

Details of this general impression may be seen in Tables I – III. During the 9 flights observations were made at five-minute intervals. Of the total number of these, 167 in all, only 3 showed cirrus to be absent. Table I shows that on the 56 occasions when the observer had confidence in his observations 41, or about three-quarters, show the cirrus to have been, to at least some extent, associated with cumulonimbus tops. Table II shows that on some occasions cirrus was present above the main sheet. Again on two-thirds (20 out of 30) of the occasions the cirrus was associated with cumulonimbus tops. There were however 18 occasions when cumulonimbus clouds penetrated the main cirrus sheet without further cirrus formation. Such differences may indicate different stages of development of the cumulonimbus clouds.

TABLE I—NUMBER OF OBSERVATIONS OF CIRRUS SHEETS OF 6/8 OR MORE AND THEIR ASSOCIATION WITH CUMULONIMBUS

Association of cirrus sheets and cumulonimbus				Cirrus sheets without cumulonimbus	Total number of observations
Entirely associated	Mostly associated	Partly associated	Not at all associated		
9	17	15	6	9	56

TABLE II—NUMBER OF OBSERVATIONS OF CIRRUS ABOVE THE MAIN CIRRUS SHEET AND THE ASSOCIATION WITH CUMULONIMBUS PENETRATING THE MAIN SHEET

Association of 'cirrus above' and cumulonimbus penetrating the main cirrus sheet				'Cirrus above' without cumulonimbus	Total number of observations
Entirely associated	Mostly associated	Partly associated	Not at all associated		
6	11	3	9	1	30

Note : there were also 18 occasions when cumulonimbus penetrated the main sheet but there was no cirrus above the sheet.

TABLE III—NUMBER OF OBSERVATIONS OF CIRRUS FROM DIFFERENT AIRCRAFT ALTITUDES

Aircraft altitude	Cirrus top below aircraft			Aircraft in cirrus cloud		Cirrus base above aircraft		
	No cloud	1/8–5/8 cloud	6/8–8/8 cloud	1/8–5/8 cloud	6/8–8/8 cloud	No cloud	1/8–5/8 cloud	6/8–8/8 cloud
feet				*number of observations*				
≤ 35,000	18	7	0	2	2	4	6	15
36–40,000	0	8	3	1	13	4	5	2
41–45,000	4	9	14	12	28	21	5	1
46,000	0	2	21	1	4	23	0	0
47,000	0	3	9	0	2	7	5	0
48,000	0	1	0	0	1	0	1	0
49,000	0	1	1	0	0	1	1	0

In Table III are shown the amounts of cirrus observed from different levels. It will be seen that there were usually only small amounts of cirrus above about 46,000 ft. The base of cirrus was observed mostly to be located between 25,000 and 35,000 ft. The highest cirrus observed was estimated to be 1/8 at 55,000 ft and about 1000 ft thick.

Several examples of cumulonimbus clouds with cirrus streamers of estimated lengths of over 100 miles were observed, particularly striking examples being seen during the outward journey between Madras and Malaya. A photograph of one of these is shown as Plate I. Such clouds have been described earlier by Frost.[1] On this occasion however cirrus streamers of great length were still attached to the parent cumulonimbus, indicating a life for the cloud of several hours.

On many occasions the presence of cirrus prevented observation of other cloud formations. There is however no doubt, as shown earlier, that much of the cirrus was engendered by cumulonimbus clouds. Indeed cumulonimbus clouds were often observed to be 'feeding' the cirrus which obviously contained embedded cumulonimbus tops. On the other hand on one flight there were unusually small amounts of cirrus, whilst only one cumulonimbus was to be seen over the whole southern half of Malaya. It was occasionally observed that some extensive sheets of cirrus were unaccompanied by cumulonimbus development and the same may be true in a number of other flights when observation was difficult.

The cumulonimbus tops were usually associated with large amounts of cirrus and were thus not visible. Along the 6000 miles flown above 40,000 ft on the 9 flights, which were in areas selected as most likely to produce cumulonimbus clouds, only 26 cumulonimbus tops were encountered. These were clouds which had penetrated the cirrus sheet, or were not surrounded by cirrus and which it was possible to approach within about 30 miles.

The main features of the cumulonimbus observations may be briefly summarized :

- (i) Cumulonimbus tops were mostly associated with large amounts of cirrus which obscured them ;
- (ii) Cumulonimbus tops infrequently penetrated the cirrus veil ;
- (iii) The average height of cumulonimbus tops was 46,000 ft ;
- (iv) The maximum height of cumulonimbus tops was 51,000 ft ;
- (v) The separation of cumulonimbus tops at heights above 40,000 ft exceeded 100 miles on 75 per cent of occasions and was never less than 20 miles ;

(vi) It was not possible to arrive, with reasonable certainty, at any conclusions regarding the distribution of cumulonimbus clouds with orographic features, but the general impression was that the distribution was largely random.

These results are in substantial agreement with those of Deshpande,[2] who collected a much greater volume of observations relating to India and Pakistan over six south-west monsoon seasons. He found less than 1 per cent of tops reaching above 52,500 ft (true).

Relationship of cloud tops to the tropopause.—There was inevitably a degree of subjectivity in assessing the tropopause level from the sparse network of radiosondes over the routes flown. However on 4 of the 9 flights there is little doubt that cloud was below the tropopause by amounts between about 2000 and 9000 ft. On 3 flights cumulonimbus tops were found at tropopause level, whilst on the other two, cloud was found about 5000 ft within a diffuse tropopause zone. This cloud was observed to be cirrus, but the turbulence within it suggests that cumulonimbus may also have been present. It seems probable that these observations were of cumulonimbus in the glaciated, degenerating phase.

Conclusion.—The present observations are too few to be able to draw firm conclusions from them in isolation. However they agree well with Deshpande's results and the two sets of results taken together suggest that the distribution of maximum height of cloud top may be fairly uniform over a wide area of south-east Asia during the south-west monsoon season. At 50,000 ft the chance is high that a pilot will be on top of all cloud or cloud amounts will be small, but at lower heights the chance of encountering cumulonimbus clouds or cirrus concealing cumulonimbus increases rapidly.

Acknowledgements.—The authors' thanks are due to Mr. B. W. Butler and Mr. D. M. Pusey who made the observations, as well as to the Royal Air Force crews who flew the aircraft under difficult conditions.

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A SIMPLIFIED CALCULATION OF MAXIMUM VERTICAL VELOCITIES IN MOUNTAIN LEE WAVES

By S. A. CASSWELL

Introduction.—The general conditions most favourable for the occurrence of waves to the lee of mountains, and the conditions for lee waves to be associated with large vertical velocities are well known, mainly as a result of theoretical studies by Scorer.[1] However, the application of the theory in practical cases is difficult, especially in the assessment of vertical velocities, a problem of considerable importance in aviation.

In the theory, the occurrence and properties of lee waves are shown to depend on the vertical variation of the parameter l where, neglecting the rate of change of wind shear with height,

$$l^2 = \frac{g}{U^2} \frac{1}{\theta} \frac{\partial \theta}{\partial z} = \frac{S}{U^2} \qquad \ldots (1)$$

where g = acceleration due to gravity
U = horizontal wind speed
θ = potential temperature
z = height
S = static stability.

If one considers a given airstream in detail, computation of the wave-length(s) and other properties of the flow is a formidable undertaking, necessitating the use of an electronic computer. For this reason Foldvik[2] proposed that an approximation to the profile of l should be obtained from an exponential function uniquely determined by two parameters only. Thus he put

$$l = l_0 e^{-cz} \qquad \ldots (2)$$

and found values of l_0 and c to give a best fit to the observed profile of l computed using 100-mb layers. The advantage of this scheme is that the variation of l is reduced to two parameters and the lee wavelengths, etc., can then be calculated in a straightforward manner. Foldvik showed that results so obtained compare favourably with observations, and with those from more elaborate calculations. His method, however, is still too time-consuming for application in routine forecasting, taking perhaps 20 minutes for one upper air sounding. In this paper additional simplifications are proposed to speed up the calculations still further so that the results can be obtained in about 2 minutes. Basically, the present method makes a simplification by obtaining l in terms of two parameters at an early stage of the work, instead of after the rather lengthy process of calculation of the l-profile.

The simplified method.—In lee-wave conditions there is typically a stable layer located somewhere in the lower troposphere, with less stable air above. It is therefore proposed to represent the atmosphere approximately by two layers only, namely 1000 to 700 mb and 700 to 300 mb, and to obtain an approximation to the profile of l by using the exponential equation (2) made to fit the observed values of l found for the layers centred at 850 and 500 mb.

The static stability S can be obtained from the equation :

$$S = \frac{g}{\theta} \frac{\partial \theta}{\partial z} = -\frac{g^2 \rho}{\theta} \frac{\partial \theta}{\partial p} = \frac{g^2}{RT} \left(K - \frac{p}{T} \frac{\partial T}{\partial p} \right) \qquad \ldots (3)$$

where $K = R/c_p$ and T, p ρ, R, c_p have their usual meanings.

By taking finite differences in the vertical and inserting values for the constants,

$$S = \frac{0{\cdot}366}{T_m} \left(0{\cdot}288 - \frac{p_m}{T_m} \frac{\Delta T}{\Delta p} \right) \text{ in terms of (seconds)}^{-2} \qquad \ldots (4)$$

where T_m and p_m are means over the layer.

This expression can be evaluated for the lower and upper layers by using appropriate values for T_m, p_m, ΔT and Δp as follows :

	T_m °K	p_m millibars	Δp	ΔT
Lower layer ...	273	850	300	$T_{1000} - T_{700}$
Upper layer ...	250	500	400	$T_{700} - T_{300}$

A smoothed temperature curve is used, as in Foldvik's method, to obtain ΔT. If the tropopause is below 300 mb the tropospheric curve is extended to 300 mb to obtain ΔT; in such examples the stratospheric temperatures are ignored because they are not representative of the layers examined.

From equation (1), $l = S^{\frac{1}{2}}/U$ . . . (5)

where U is the component of the wind across the mountain range for the particular layer used for l and S. Graphs to obtain l_{850} and l_{500}, the values

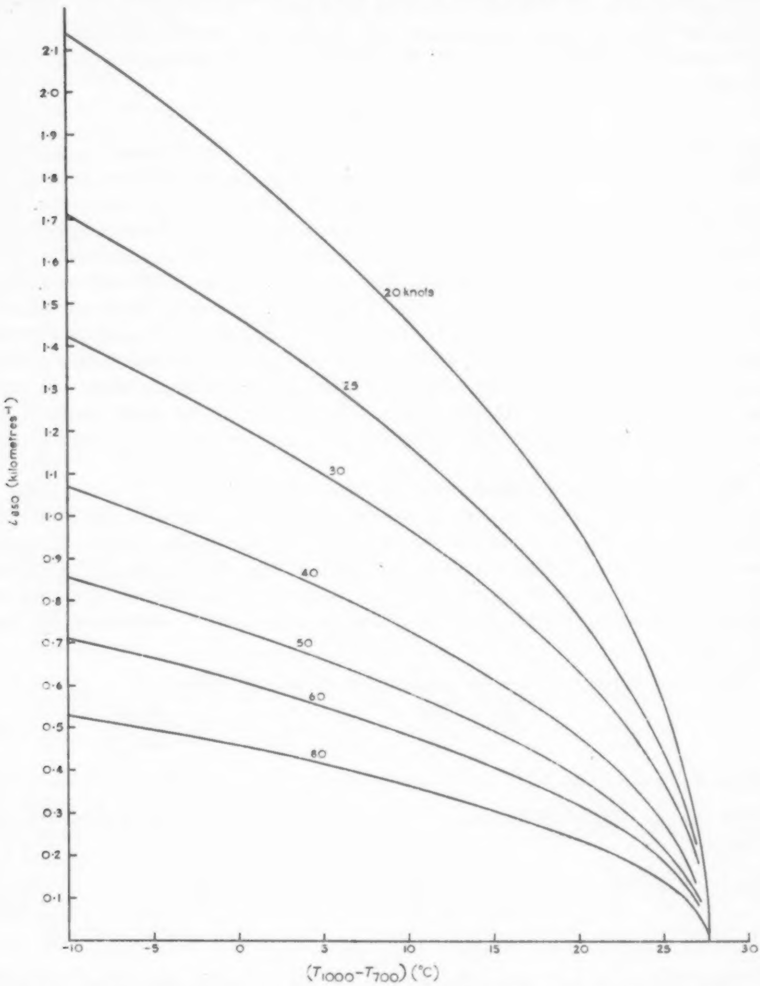


FIGURE 1—GRAPHS USED TO OBTAIN l_{850} FROM $(T_{1000} - T_{700})$ AND U_{850}

of l at 850 mb and 500 mb, are shown in Figures 1 and 2 which have been computed from equations (4) and (5) using the values of S obtained for the lower and upper layers.

Substituting l_{850} and l_{500} in turn in Foldvik's exponential formula (2), values of l_0 and c can be obtained.

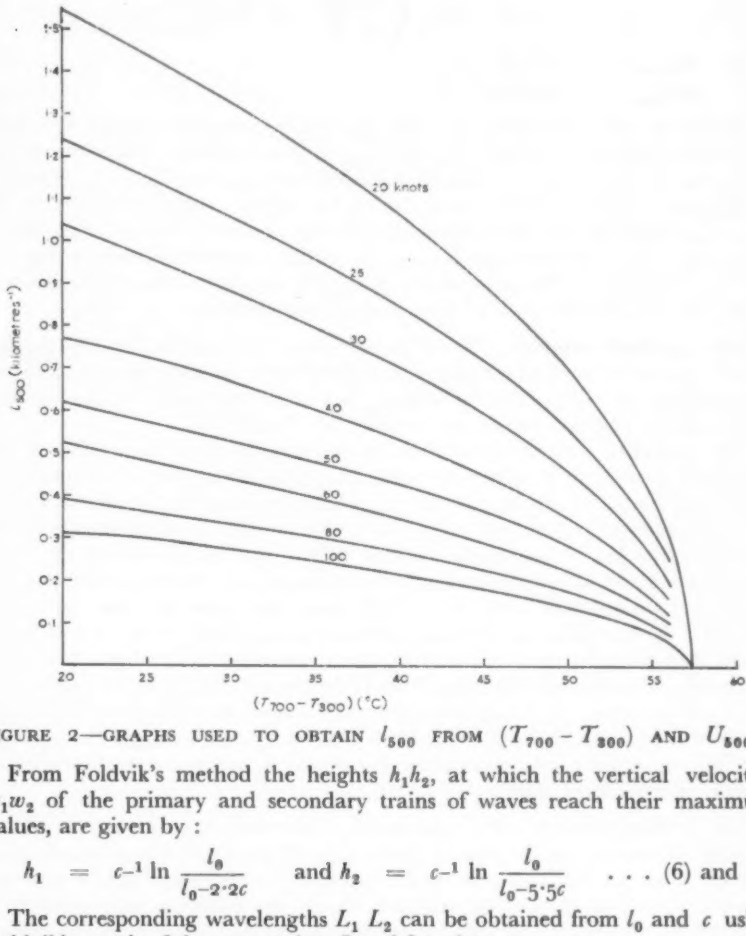


FIGURE 2—GRAPHS USED TO OBTAIN l_{500} FROM $(T_{700} - T_{300})$ AND U_{500}

From Foldvik's method the heights $h_1 h_2$, at which the vertical velocities $w_1 w_2$ of the primary and secondary trains of waves reach their maximum values, are given by :

$$h_1 = c^{-1} \ln \frac{l_0}{l_0 - 2{\cdot}2c} \quad \text{and } h_2 = c^{-1} \ln \frac{l_0}{l_0 - 5{\cdot}5c} \qquad \ldots \text{(6) and (7)}$$

The corresponding wavelengths L_1 L_2 can be obtained from l_0 and c using Foldvik's graph of the appropriate Bessel function.

The values of the maximum vertical velocities can then be obtained from his approximations, thus :

$$(w_1)_{\max} = \left(2{\cdot}5 + \frac{0{\cdot}7}{cL_1}\right) HcU_0 \left(\frac{\rho_0}{\rho_1}\right)^{\frac{1}{2}} \qquad \ldots (8)$$

and $$(w_2)_{\max} = 3{\cdot}2 \; HcU_0\left(\frac{\rho_0}{\rho_2}\right)^{\frac{1}{2}} \qquad \ldots (9)$$

where H is the height of the mountain barrier and for practical purposes U_0 can be taken as the wind velocity at about the level of H in the free air, and ρ_0, ρ_1 and ρ_2 refer to the density at heights 0, h_1 and h_2.

$$\text{Let } \left(2{\cdot}5 + \frac{0{\cdot}7}{cL_1}\right) c \left(\frac{\rho_0}{\rho_1}\right)^{\frac{1}{2}} = C_1 \qquad \ldots (10)$$

$$\text{and } 3{\cdot}2c \left(\frac{\rho_0}{\rho_2}\right)^{\frac{1}{2}} = C_2. \qquad \ldots (11)$$

$$\text{Then } (w_1)_{max} = HU_0C_1 \qquad \ldots (12)$$

$$(w_2)_{max} = HU_0C_2. \qquad \ldots (13)$$

Values of the parameters C_1 and C_2 can be obtained graphically from equations (10) and (11) with l_{850} and l_{500} as the variables. Thus the values of L_1, h_1, C_1, L_2, h_2 and C_2 can be obtained from l_{850} and l_{500} and are shown in Figures 3 and 4. These were drawn by taking a grid of points on the $l_{850}-l_{500}$ diagram and first calculating for each point the values of l_0 and c, next from these determining L_1, L_2, h_1 and h_2, and finally calculating C_1 and C_2. Isopleths of the required six items were then drawn freehand, dividing them into two graphs, each of three items for convenience.

The vertical velocity.—It will be seen that wavelengths and the heights of the maximum vertical components depend only on the airstream, and are independent of the mountain height, but that the value of the vertical component is proportional to this height.

It is generally recognized that the lee slope is the important factor of the mountain profile, so it is not the mountain peak elevation above mean sea level that should be used for H but the difference between the general height of the mountain barrier in the vicinity of the lee slope and the height of the ground to its lee. Most of the various factors that cannot easily be taken into account tend to reduce the vertical component, e.g. friction effect, possible separation of the flow from the surface (say with cold air over the lower ground), though some factors such as overlapping effects from two or more ridges of mountains could either increase or decrease the values. A general figure of 300 metres was taken by Foldvik for the value of H in the neighbourhood of Leuchars. It is suggested that this value be used generally within the British Isles and the result taken as a general figure that might be expected over an appreciable area on a particular occasion, but it cannot be expected to give extreme local values.

Use in forecasting.—The mountains of the British Isles have lee slopes in most directions, so for general forecasting of lee waves the gradient wind can be taken as the horizontal wind speed U_0 at the ridge height and the upper-level winds should be resolved along the gradient wind direction. The effects calculated will then be for the region that lies directly to the lee of the mountain range, with, usually, smaller effects where the lee slope is not perpendicular to the wind direction. In forecasting for a specific small area components perpendicular to the specified ridge would be used at all levels required.

Limits and limitations.—There are various requirements before lee waves can be expected, and some limitations of the present method of calculation.

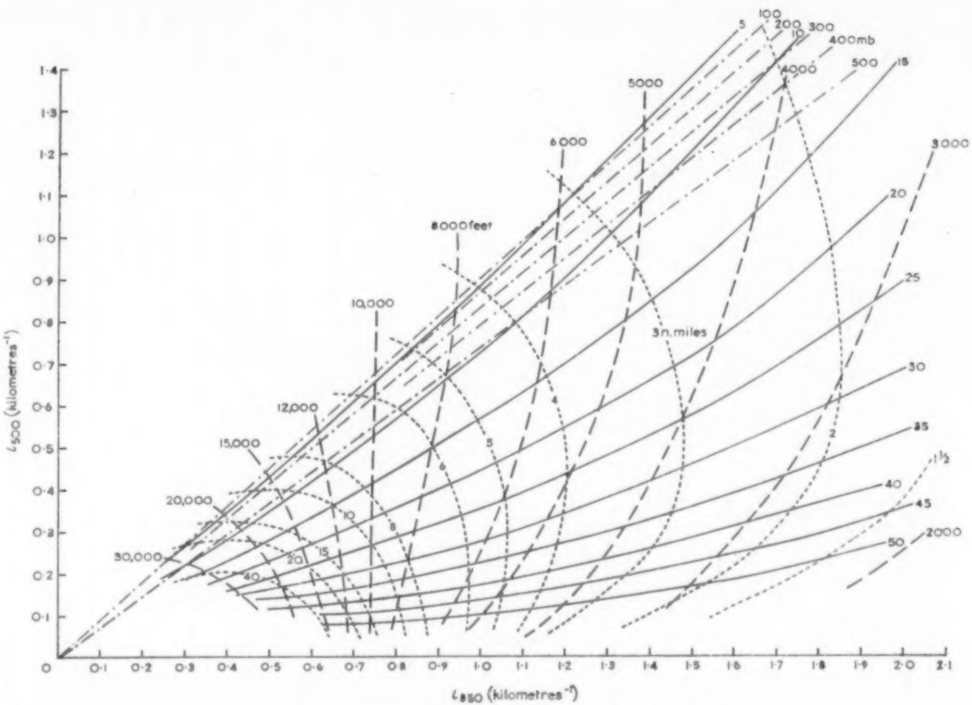


FIGURE 3—GRAPHS USED TO OBTAIN L_1, h_1 AND C_1

——— Values of C_1 (see text) — — — Values of h_1 (feet)

- - - - - Values of L_1 (nautical miles) - — - — Level of tropopause (millibars) for limiting value of l_{850}/l_{500}

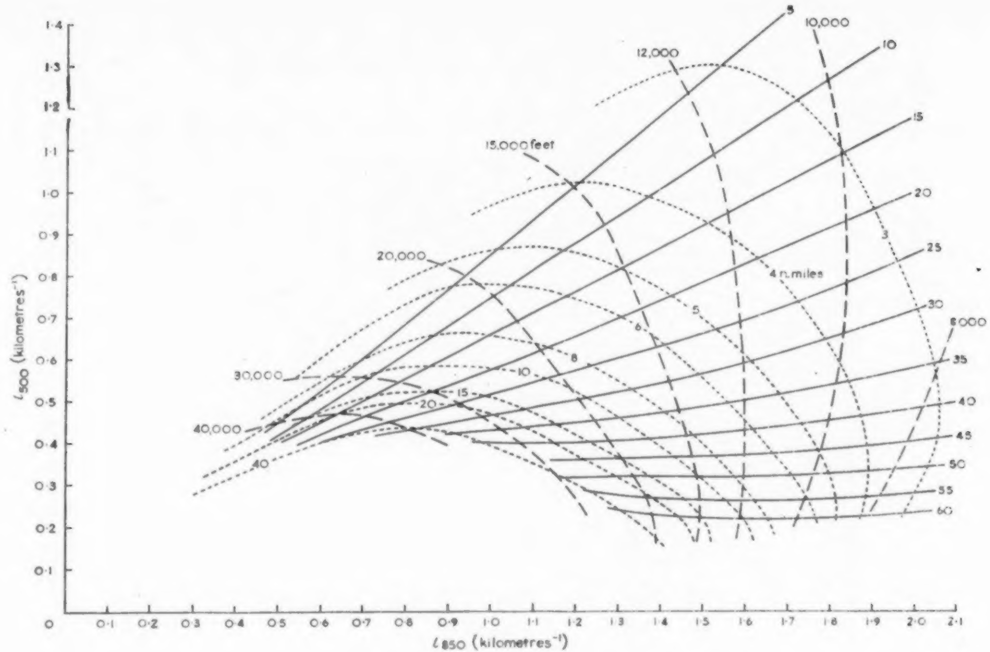


FIGURE 4—GRAPHS USED TO OBTAIN L_2, h_2 AND C_2

——— Values of C_2 (see text) — — — Values of h_2 (feet)

- - - - Values of L_2 (nautical miles)

A minimum wind component across the mountain barrier of between 7 and 15 metres/second is generally considered necessary for small mountains and the wind direction should be within about 30 degrees of the perpendicular to the line of the lee ridge, and should change little with height (*WMO Tech. Note No.* 34, pp. 29, 42, 48, 119[3]). A marked decrease, with height, of the component across the ridge will limit the wave activity to below this level. (*WMO Tech. Note No.* 34, Figure 46 *b*).

No marked waves will occur unless l decreases appreciably with height. One of Foldvik's approximations requires that l_0 should be greater than 1·5 times the minimum value of l. If this requirement is not fulfilled the calculations are invalid. It seems likely however that marked waves should not be expected in these cases and this is allowed for in Figure 3 by the straight lines through the origin, marked 100, 200, etc. mb, which are drawn on the assumption, generally true, that the minimum value of l is at the tropopause. The line corresponding to the tropopause level should be noted, and if the plot of l_{500} against l_{850} lies above this then marked waves are not expected.

No use is made of stratospheric winds and temperatures in the present method, which is concerned chiefly with waves in the lower levels. Any waves calculated to have a maximum vertical velocity above the tropopause are not likely to be real, and if the maximum is near the tropopause the values obtained may be appreciably in error. Waves at lower levels however are little affected by the marked change in value of l at the tropopause (Corby and Sawyer[4]).

Comparison with other methods.—When marked waves occur, large vertical velocities extend over only short distances perpendicular to the line of the mountains, but over much longer distances parallel to this line. The effect on an aircraft can be very serious if it should be flying at the appropriate height, place and course, whilst other aircraft flying across the same area may experience little effect. Thus few aircraft observations are available giving details sufficient to allow comparison with calculated values of vertical motion.

However, another characteristic of the motion, the wavelength, would not be expected to vary so greatly with height as does the vertical velocity. One of the best series of observations available is that of Corby[5] who calculated the wavelengths of lee waves from the changes in vertical motion found in routine radiosonde ascents from Leuchars. This series has been used by Foldvik[2] and by Wallington and Portnall.[6] A comparison with the present method is given in Table I. In the comparison with the observed wavelength, there is the complication that the temperatures are measured in the airstream that is already disturbed by the wave motion. Both the suggested method and the full exponential one are somewhat subjective, so that some appreciable differences are to be expected. Generally, however, these differences are not found to be large.

The calculated maximum vertical velocity in the primary wave train is within 20 per cent of that obtained by the full exponential method except for the following four examples (the numbering is taken from Table I) :

(i) No. 3. — The l-trace has an unusual shape due to a marked decrease of wind above 800 mb, followed by an increase above 650 mb. The

TABLE I—COMPARISON BETWEEN OBSERVED AND VARIOUSLY COMPUTED LEE-WAVE CHARACTERISTICS

Example No.	Date Time (GMT)	Observed λ (Corby)	Computed λ (Wallington and Portnall)	COMPUTED VALUES—FOLDVIK λ	Maximum vertical velocity	Height of max.	l_0	ε	COMPUTED VALUES—PRESENT METHOD λ	Maximum vertical velocity	Height of max.	l_0	ε
		kilometres		*km*	*m/s*	*km*	*km*$^{-1}$	*km*$^{-1}$	*km*	*m/s*	*km*	*km*$^{-1}$	*km*$^{-1}$
1	4.11.53	13·3	14·6	15·0	3·0	2·7	1·06	0·21	17	2·5	3·2	0·90	0·17
	1400												
2	18.11.53	13·3	15·0	13·6	2·7	2·6	1·05	0·17	14	3·2	2·8	1·08	0·19
	0400												
3	20.11.53	8·9	4·5	6·3	3·2	1·4	1·75	0·19	9	2·5	2·0	1·26	0·14
	0400		8·9	13·4	3·8	4·8			20	3·7	7·3		
4	30.11.53	26·7	–	>50	–	–	0·74	0·24	55	5·1	6·7	0·63	0·19
	0200												
	Aldergrove			23·0	4·9	2·9	1·15	0·31	24	4·9	3·3	1·07	0·29
	21.12.53	10·0	13·0	13·2	4·0	2·3	1·23	0·24	17	4·2	2·8	1·09	0·25
	1400												
6	3.1.54	18·5	17·0	19·3	4·6	2·9	1·05	0·25	17	4·4	2·9	1·07	0·23
	0300												
7	3.1.54	18·5	17·9	19·4	2·9	3·6	0·80	0·15	18	3·4	3·3	0·92	0·20
	1500												
8	4.1.54	10·0	10·0	10·9	3·4	2·0	1·35	0·23	9	3·7	1·8	1·50	0·23
	0200								39	5·5	8·5		
9	11.1.54	12·0	8·9	8·6	1·7	2·0	1·23	0·13	11	2·0	2·2	1·17	0·15
	0200		10·0	17·4	2·2	6·7			32	3·0	8·5		
			15·5										
10	11.1.54	5·9	7·6	7·5	2·0	1·7	1·45	0·16	8	1·7	1·9	1·33	0·12
	1400		12·0*	15·9	2·6	5·9			15	2·2	6·1		
11	12·1.54	8·9	11·0	12·9	1·5	3·3	0·75	0·062	12	1·0†	3·4	0·68	0·032
	1600			21·4	2·0	9·8			15	1·0†	9·2		
				44·0									
12	14.1.54	10·4	–	16·2	1·4	3·6	0·70	0·082	18	1·2	4·3	0·61	0·07
	0200												
	Stornoway			15·0	1·4	3·2	0·84	0·12	17	1·4	3·7	0·78	0·12
13	23.1.54	5·6	5·7	5·1	0·8	1·4	1·74	0·11	5	1·1	1·3	1·85	0·13
	1400		7·4*	7·3	0·8	3·9			7	1·1	3·7		
			8·3*	11·2	1·1	7·9							
14	24.1.54	4·8	9·1*	12·4	2·8	2·3	1·20	0·21	11	2·2	2·3	1·14	0·15
	1400		11·8*										
	Aldergrove			15·3	2·1	4·8	0·71	0·078	18	2·4	4·0	0·70	0·102
15	21.3.54	8·7	–	22·2	3·8	3·2	1·00	0·25	30	3·4	4·1	0·86	0·23
	0200												
	Aldergrove			12·0	4·0	2·0	1·50	0·32	12	3·8	2·1	1·41	0·30
16	11.4.54	8·7	7·8	8·4	1·7	2·0	1·21	0·11	9	1·8	2·1	1·18	0·11
	1400		10·6*	14·4	2·0	6·3			17	2·3	6·7		
17	14.4.54	24·1	–	25·9	2·6	4·7	0·60	0·11	31	2·9	5·5	0·59	0·13
	1500												
18	15.4.54	18·7	23·4	23·3	2·8	4·1	0·70	0·14	31	2·3	5·5	0·55	0·11
	0200												
19	15.4.54	14·4	11·5	13·7	2·6	2·4	1·20	0·23	12	2·6	2·1	1·36	0·26
	1400												

Computations are from Leuchars radiosonde ascents except where otherwise stated. More than one wave system is shown on some dates.
λ = Wavelength. * Accuracy doubtful. † Accuracy doubtful, see text

values from the full exponential method are very subjective, see Figure 5, 20.11.53. The present calculation gives a more accurate wavelength, according to the observed value.

(ii) No. 11. — This is an example where the exponential method is not valid owing to the slow decrease of l with height. The plot on Figure 3 falls just outside the limit since the tropopause is at 200 mb, so that marked waves would not be expected. Both calculations do show the vertical motion to be relatively slight.

(iii) No. 13. — The values are very small.

(iv) No. 14. — Winds decrease above 600 mb. None of the methods is successful in obtaining the observed wavelength.

The other important characteristic concerning aviation is the height of the maximum vertical component. This differs according to the method used and the difference is more than 0·5 km (1600 feet) in the following examples :

(*a*) No. 3. — See (i) above.

(*b*) No. 12 (Leuchars). — The numerical calculation of Wallington and Portnall[6] using a computer, failed to give a result in this case.

(*c*) No. 14 (Aldergrove). — See (iv) above.

(*d*) Nos. 15 and 17. — These are also examples for which the computer failed to give a result.

(*e*) No. 18. — Values with the full exponential method are rather subjective, see Figure 5, 15.4.54.

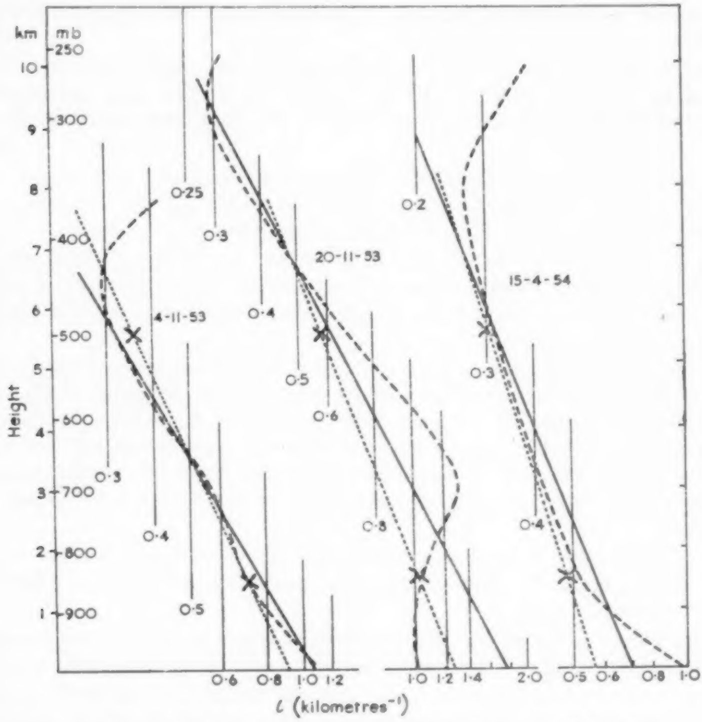


FIGURE 5—COMPARISONS OF THREE METHODS OF PRODUCING l-CURVES

——— Exponential approximation of Foldvik — — — l-curves

x Values at 850 and 500 mb calculated by the present method. These points are joined by a dotted line for comparison.

Units.—In the calculations and for comparisons metric units have been used, but for practical use in Figures 1 to 4 they have been converted to the more usual aviation units of nautical miles and feet, with horizontal speeds in knots and vertical speeds in feet per minute, but l is simply transferred from figure to figure in units of km^{-1}.

Use of the diagrams.—From a smoothed sounding or estimate in the appropriate air mass, obtain the temperature differences :

$T_{1000} - T_{700}$, temperature lapse between 1000 and 700 mb.

$T_{700} - T_{300}$, temperature lapse between 700 and 300 mb.

If the tropopause is below 300 mb extend the tropospheric curve to 300 mb to obtain T_{300}.

Note the pressure at the tropopause.

From upper wind data or charts obtain :

U_0, the wind speed across the mountains, say the gradient wind or 2000-ft wind for mountain heights such as those of the British Isles ;

U_{850}, the wind speed at 850 mb, or preferably the mean between the mountain top and 700 mb ;

U_{500}, the wind speed at 500 mb, or preferably the mean between 700 and 300 mb.

If U_0 is less than about 20 kt then no marked waves can be expected. They should not be expected where the direction of U_0 is at an angle greater than about 30 degrees from the perpendicular to the ridge line nearest to the lee slope.

If waves are not ruled out by the above conditions, then
from $T_{1000} - T_{700}$ and U_{850} use Figure 1 to obtain l_{850},
from $T_{700} - T_{300}$ and U_{500} use Figure 2 to obtain l_{500}.
Using in Figure 3 the values just obtained for l_{850} and l_{500}, read off the wavelength and the height of the maximum vertical velocity together with a value from the third set of lines, which when multiplied by U_0 will give the maximum vertical velocity.

If the point on the graph lies above the pressure line corresponding to the level of the tropopause then no waves are expected. If the height of the maximum vertical component is higher than the level of the tropopause then the values are not reliable but marked waves in the lower levels are not to be expected. If this level is near the tropopause then the values may be appreciably in error, but again, marked waves in the lower levels are not expected.

If there is a marked decrease of wind speed at any level, or a marked change in direction, say more than 30 degrees, then wave activity is not likely to extend above this level.

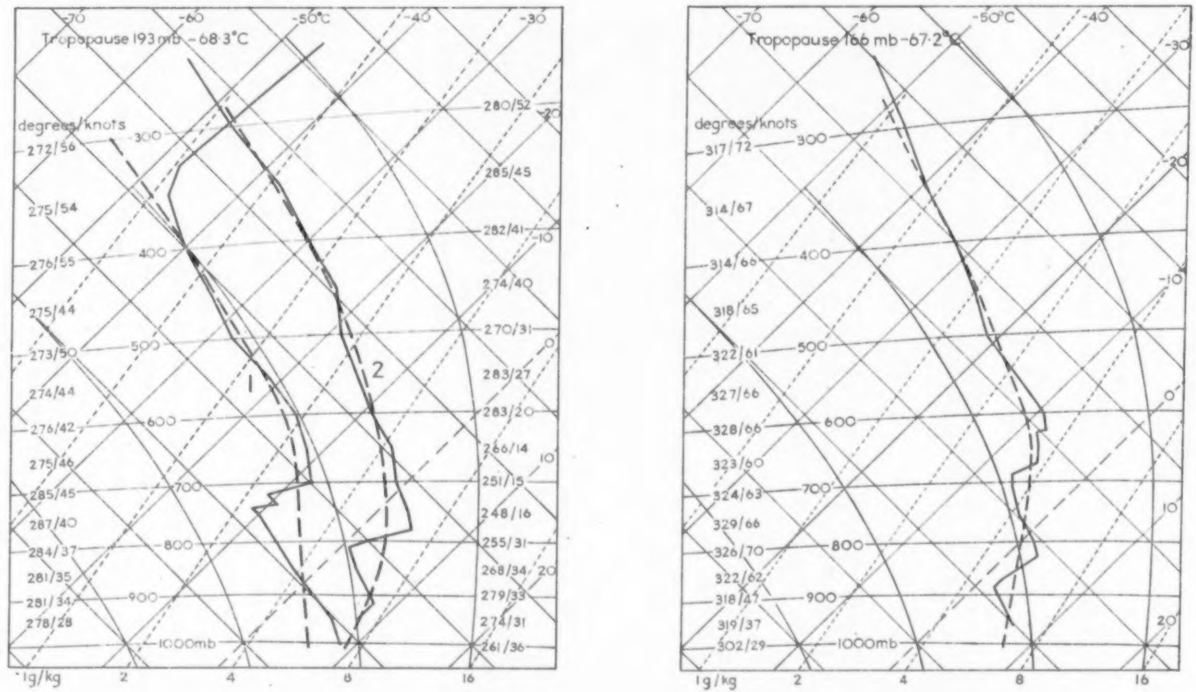
From Figure 4, values for a further series of waves at a higher level may be found in certain cases. The limitations mentioned above also apply to these.

The wavelength of the lee wave and the height of maximum vertical velocity do not vary with the ridge height, i.e. the height of the mountain above the surrounding country. The vertical velocities are proportional to this height. In Figures 3 and 4 the factors are for a ridge height of 1000 feet and give vertical velocities in feet per minute if wind speeds are in knots.

Examples.—Figures 6 (*a*) and (*b*) give examples of the smoothing process. The details extracted and the computed values are given in Table II.

TABLE II—THREE EXAMPLES BASED ON THE LEUCHARS RADIOSONDE ASCENTS IN FIGURE 5

Date	4.11.53	20.11.53	15.4.54
Time (GMT) ...	1400	0400	0200
$T_{1000} - T_{700}$ (°C)	15	11	12
$T_{700} - T_{300}$ (°C)	46·5	45	43
U_0 (knots) ...	28	33	37
U_{850} (knots) ...	35	28	60
U_{500} (knots) ...	48	33	64
l_{850} (km^{-1}) ...	0·71	1·01	0·47
l_{500} (km^{-1}) ...	0·36	0·57	0·30
L_1 (km)	17	9	32
(n. miles) ...	9	5	18
h_1 (km)	3·2	2·0	5·5
(feet)... ...	10,700	7000	18,000
C_1	17·5	15	12·5
w_1 (m/s) ...	2·5	2·5	2·3
(ft/min) ...	490	500	460



(*a*) 1400 GMT on 4 November 1953 – curves (1)
0400 GMT on 20 November 1953 – curves (2)

(*b*) 0200 GMT on 15 April 1954

FIGURE 6—LEUCHARS RADIOSONDE OBSERVATIONS AND SMOOTHED TEMPERATURE CURVES

——— Observed temperatures — — — Smoothed curves

Acknowledgement.—Thanks are expressed to Mr. G. A. Corby for very valuable help.

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551.509.324.2:551.509.542

THE FORECASTING OF SHOWER ACTIVITY IN AIRSTREAMS FROM THE NORTH-WEST QUARTER OVER NORTH-WEST ENGLAND IN SUMMERTIME

By C. A. S. LOWNDES

Introduction. — In earlier papers [1,2] a study was made of the shower activity in airstreams from the north-west quarter over south-east England and south-west England in summertime and the relative usefulness of a number of predictors for forecasting shower activity, thunder and hail was evaluated. This paper deals in the same way with the problem of forecasting shower activity over north-west England in summertime. The investigation was again restricted to airstreams which approached the British Isles from the north-west quarter. This was achieved by including only those days when the surface isobars over north-west England and the northern Irish Sea at midday showed a flow from between west and north-west inclusive and the polar front lay to the south of the area or had cleared it by 0600 GMT. Occasions were not included if a front was situated over north-west England between 0900 and 2100 GMT or if the precipitation was not mainly showery. The classification of the intensity of shower activity was based on reports from six stations in the months May to September during the period 1953–63, excluding 1961 when data from one of the stations was not available. From 1953–60 the stations were Silloth, Ronaldsway, Squires Gate, Manchester, Valley and Shawbury. For 1962 and 1963, Carlisle was used instead of Silloth. From the Beaufort letters in the *Daily Weather Report* the total number of mentions of slight, moderate and heavy showers at the six stations during the period 0900 to 2100 GMT was obtained for each day. From these figures, the intensity of shower activity was classified as follows :

A Widespread showers with a good proportion of moderate or heavy showers. (6 or more mentions of showers ; more than 25 per cent moderate or heavy showers).

B Widespread showers with few moderate or heavy showers. (6 or more mentions of showers ; 25 per cent or less of moderate or heavy showers).

C Few showers (less than 6 mentions of showers).

D No showers.

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PLATE I—CUMULONIMBUS WITH CIRRUS STREAMER BETWEEN MADRAS AND MALAYA

See page 67.

Photograph by P. L. Baylis

(*a*) Damage in the orchard.

Photograph by P. L. Baylis

(*b*) Damage in the orchard.

PLATE II (*a*)–(*d*)—DAMAGE CAUSED BY THE TORNADO AT WISLEY ON 21 JULY 1965

See page 92.

Photograph by P. L. Baylis

(*c*) Damage in the orchard.

Photograph by P. L. Baylis

(*d*) Damage to a tree close to the Portsmouth road.

Photograph by R. K. Pilsbury

PLATE III—FROST PATTERNS ON A GLASS DOOR ON 29 DECEMBER 1965

Photograph by R. K. Pilsbury

PLATE IV—FROST PATTERNS ON A GLASS DOOR ON 29 DECEMBER 1965

See page 94.

A note was made of thunder or hail reported between 0900 and 2100 GMT at any of the stations. Surface reports were supplemented by sferic (atmospheris) observations during the same hours of the day.

The factors which were considered were essentially the same as in the two previous investigations.[1,2]

Association with surface synoptic features.—

The position of the associated depression at midday.—Table I shows for each class of shower activity the number of occasions when the depression with which the polar air was associated was situated in a particular locality.

TABLE I—SHOWER ACTIVITY RELATED TO POSITION OF ASSOCIATED DEPRESSION AT MIDDAY (MAY TO SEPTEMBER 1953–60, 1962–63)

Position of depression	Class of shower activity *A*	*B*	*C*	*D*
	number of occasions			
Arctic	0	1	5	1
Iceland region	0	2	4	0
Norwegian Sea	4	9	11	2
Scandinavia	9	16	11	1
North of Scotland ...	12	7	8	2
West of Scotland ...	0	0	3	0
Scotland...	3	4	0	0
North Sea	10	7	6	0
Denmark	1	1	2	2
Poland	0	0	1	0
All areas	39	47	51	8

On all 7 occasions when the depression was situated over Scotland and on 74 per cent of occasions when the depression was over the North Sea there were widespread showers (classes *A* and *B*) over north-west England. When the depression was situated north of Scotland or over Scandinavia, there were widespread showers on about 67 per cent of occasions. With the depression situated over the Norwegian Sea there were widespread showers (classes *A* and *B*) on 50 per cent of occasions and few showers or no showers (classes *C* and *D*) on the other 50 per cent of occasions. In general, the nearer the depression was to the British Isles, the more intense was the shower activity in north-west England. This suggests that the isobaric curvature and the level of surface pressure over the British Isles might be useful predictors.

The curvature of the surface isobars.—On a number of days with widespread showers, a surface trough moved eastwards or southwards across north-west England. Of the troughs which moved eastwards, about half were major features with the trough axis some 600 to 1000 miles in length and about half were minor perturbations with the trough axis some 200 to 600 miles in length. All the troughs which moved southwards were minor perturbations. Table II shows the number of these occasions for each class of shower activity.

TABLE II—SHOWER ACTIVITY RELATED TO THE CURVATURE OF THE SURFACE ISOBARS OVER NORTH-WEST ENGLAND (MAY TO SEPTEMBER 1953–60, 1962–63)

	Class of shower activity *A*	*B*	*C*	*D*
	number of occasions			
Surface trough moved eastwards across north-west England	11	4	1	0
Surface trough moved southwards across north-west England	7	3	2	0
Uniform cyclonic isobars over north-west England... ...	8	10	1	0
Neither surface trough nor uniform cyclonic isobars ...	13	30	47	8
Total	39	47	51	8

On 46 per cent of occasions of widespread showers with a good proportion of moderate or heavy showers (class *A*) a surface trough moved eastwards or southwards across north-west England. Of the 8 days on which a major surface trough moved across north-west England, 7 were associated with widespread showers (classes *A* and *B*) and 5 with thunder. Of the 20 days on which a minor perturbation moved across north-west England, 18 (90 per cent) were associated with widespread showers and 16 (80 per cent) with thunder. Of the 19 days with uniform cyclonic isobars over north-west England, 18 (95 per cent) were associated with widespread showers and 6 (32 per cent) with thunder. There was only one occasion of widespread showers when the isobars over north-west England were anticyclonic. On 93 per cent of occasions of few showers or no showers (classes *C* and *D*) there were neither surface troughs nor uniform cyclonic isobars. On 29 per cent of occasions of few showers or no showers, the isobars over north-west England were anticyclonic.

Association with 700 mb temperature and surface pressure.—The following data were extracted :

(i) The 700 mb temperature anomaly at Liverpool for 1200 GMT (1500 GMT before 1957). The anomaly was based on the 5-day mean temperatures given in Table III.

(ii) The mean sea level pressure at Squires Gate for 1200 GMT.

TABLE III—FIVE-DAY MEAN 700 MB TEMPERATURE AT LIVERPOOL* (FAZAKERLEY) IN °C

Period	Mean	Period	Mean	Period	Mean
1– 5 May	−7	30 June– 4 July	−1	29 Aug.– 2 Sep.	−2
6–10	−6	5– 9 July	−1	3– 7 Sep.	−2
11–15	−6	10–14	−1	8–12	−2
16–20	−5	15–19	−1	13–17	−3
21–25	−5	20–24	−1	18–22	−3
26–30	−4	25–29	−1	23–27	−3
31 May– 4 June	−4	30 July– 3 Aug.	−1	28 Sep.– 2 Oct.	−3
5– 9 June	−4	4– 8 Aug.	−1		
10–14	−3	9–13	−1		
15–19	−3	14–18	−1		
20–24	−2	19–23	−1		
25–29	−2	24–28	−1		

* Obtained from 5-year monthly means for the period 1951-55. The monthly mean values were based on midday and midnight ascents and were corrected for radiation and lag errors.

Rain showers.—A diagram was plotted (Figure 1) of the 700 mb temperature anomaly at Liverpool against the mean sea level pressure at Squires Gate. The various intensities of shower activity are indicated by symbols, class *A* by a black triangle, class *B* by an open triangle, class *C* by a dot and class *D* by a cross. The diagram can be divided into two areas as indicated, area I containing most of the occasions of widespread showers and area II most of the occasions of few showers or no showers. If the diagram were used to forecast either widespread showers or few showers/no showers, a 'skill score' of 0·55 would be obtained. The skill score S[7] is defined by

$$S = \frac{\text{number of correct forecasts} - \text{number correct by chance}}{\text{total number of forecasts} - \text{number correct by chance}}$$

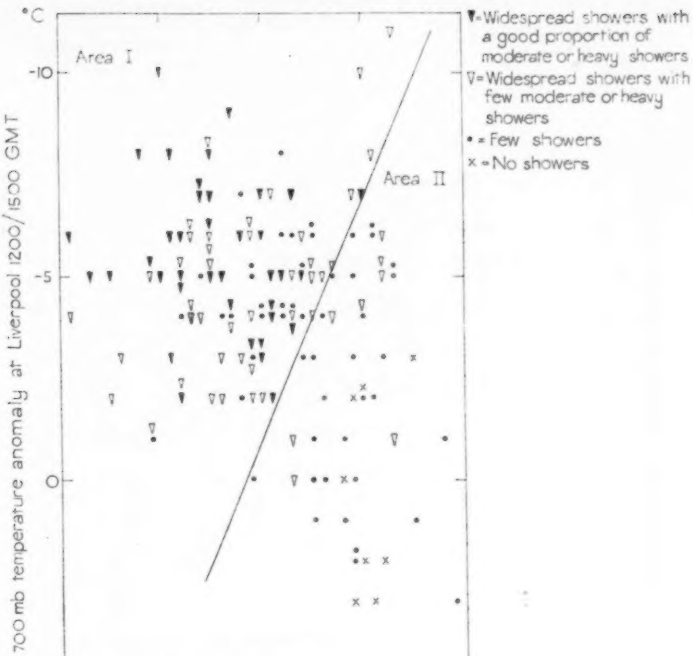

FIGURE 1—SHOWER ACTIVITY IN NORTH-WEST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

The line divides the diagram into area I containing most of the occasions of widespread showers and area II containing most of the occasions of few or no showers.

It ranges from 0 for no success to 1 for complete accuracy.

Rainfall amount.—A similar diagram (Figure 2) was plotted with symbols representing the average rainfall between 0900 and 2100 GMT for the six stations in north-west England for each day examined. The diagram is divided into the same two areas which were used in Figure 1. If the diagram were used to indicate an average rainfall of either 0·1 mm or more, or less than 0·1 mm, a skill score of 0·52 would be obtained. If it were used to indicate an average rainfall of either 0·5 mm or more, or less than 0·5 mm, a skill score of 0·41 would be obtained.

Figure 3 shows the highest and lowest rainfall amounts plotted against the average amount for the six stations in north-west England for each day examined. For an average value of up to 1 mm the highest value is likely

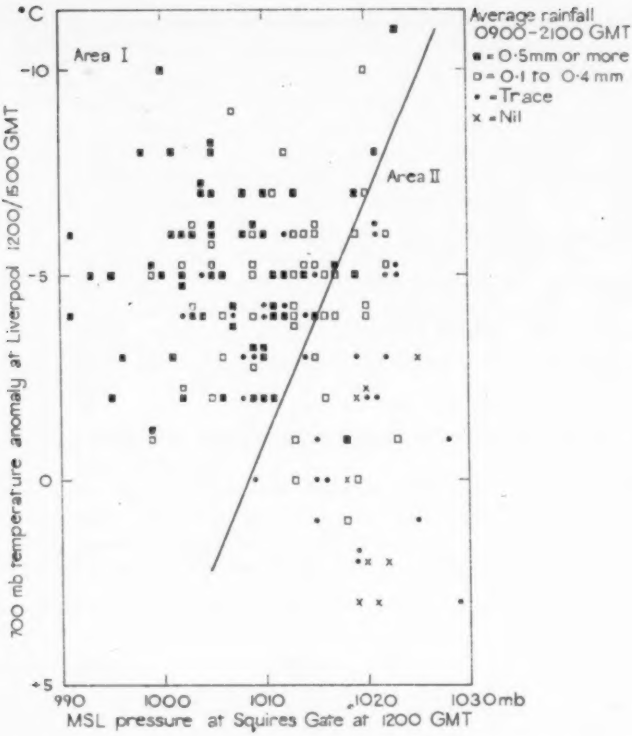

FIGURE 2—AVERAGE RAINFALL FOR SIX STATIONS IN NORTH-WEST ENGLAND FOR EACH INDIVIDUAL DAY ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

Areas I and II are the same areas as in Figure 1.

to be about four times the average, and for average values of 2 mm or more about three times the average. For an average value of up to 1·3 mm the lowest value was nil or a trace, and for an average value above 1·3 mm the lowest value varied between nil and 1 mm. It is clear that however widespread the showers, some places are likely to escape with little or no rain.

Thunder and hail.—A diagram was plotted (Figure 4) of the 700 mb temperature anomaly against mean sea level pressure with symbols representing thunder or hail. If no thunder or hail was reported, a cross was plotted. The diagram was again divided into the same two areas. If the diagram were used to indicate thunder or 'no thunder', a skill score of 0·33 would be obtained. For an indication of hail or 'no hail', a skill score of 0·11 would be obtained.

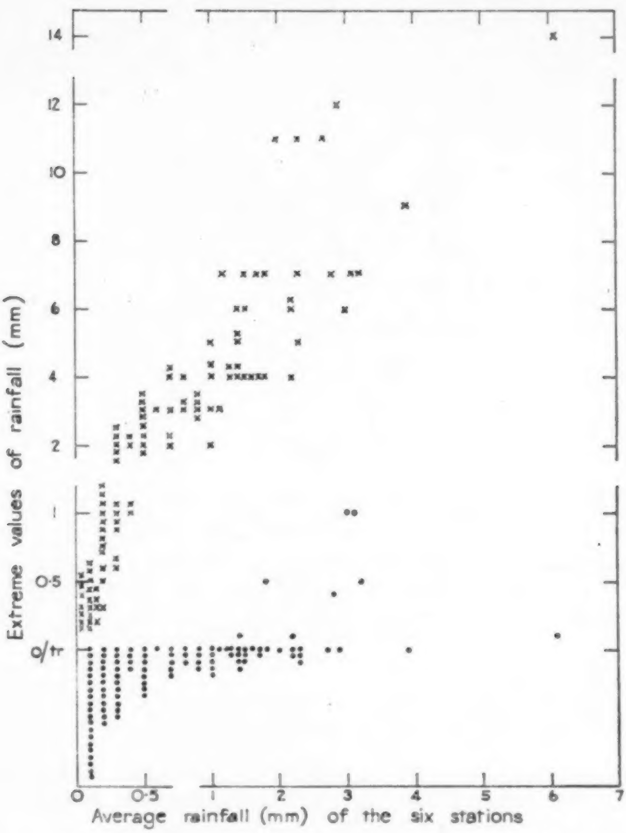

FIGURE 3—THE HIGHEST AND LOWEST RAINFALL AMOUNTS (0900–2100 GMT) ASSOCIATED WITH AVERAGE VALUES FOR SIX STATIONS IN NORTH-WEST ENGLAND

x Highest individual values . Lowest individual values

For some values of the average rainfall the lowest amount was zero on several occasions and such occasions are plotted below the o/tr line.

On all but two occasions, reports of thunder were associated with negative temperature anomalies of 3°C or more. On all but one occasion of hail, the negative temperature anomaly was 5°C or more.

Sunshine.—A study of the average duration of sunshine for the six stations in north-west England for each day examined revealed no evidence of any association between the intensity of shower activity and the duration of sunshine.

Association with 1000–500 mb thickness and surface pressure.—The 1000–500 mb thickness anomaly at Liverpool for 1200 GMT (1500 GMT before 1957) was extracted. Anomalies were measured from the 5-day mean 1000–500 mb thickness values for Liverpool given in Table IV.

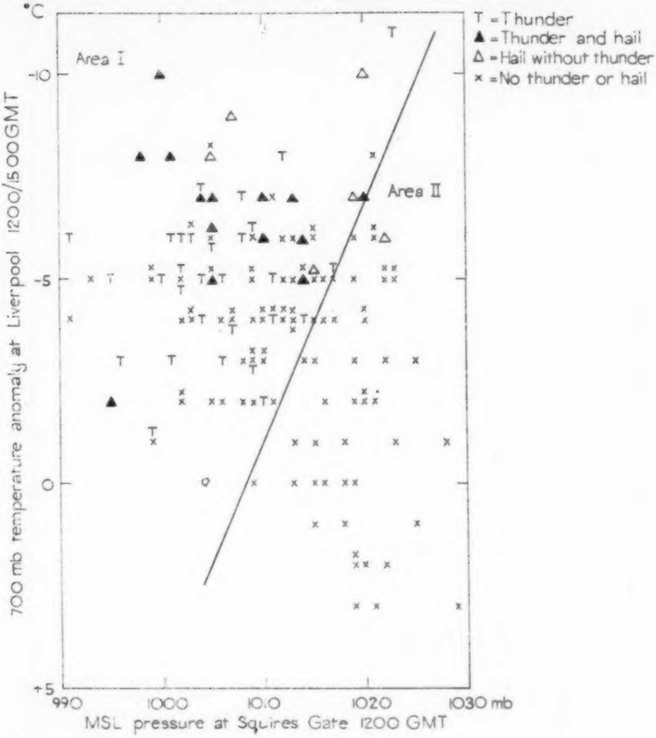

FIGURE 4—THUNDER AND HAIL IN NORTH-WEST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

Areas I and II are the same areas as in Figure 1.

TABLE IV—FIVE-DAY MEAN 1000–500 MB THICKNESS AT LIVERPOOL* (FAZAKERLEY) IN DECAMETRES

Period	Mean	Period	Mean	Period	Mean
1– 5 May	541	30 June– 4 July	552	29 Aug.– 2 Sep.	552
6–10	542	5– 9 July	553	3– 7 Sep.	551
11–15	543	10–14	554	8–12	551
16–20	544	15–19	554	13–17	550
21–25	545	20–24	554	18–22	550
26–30	546	25–29	554	23–27	549
31 May– 4 June	547	30 July– 3 Aug.	553	28 Sep.– 2 Oct.	549
5– 9 June	548	4– 8 Aug.	553		
10–14	549	9–13	553		
15–19	550	14–18	553		
20–24	551	19–23	552		
25–29	552	24–28	552		

* Obtained from 5-year monthly means for the period 1951–55. The monthly mean values were based on midday and midnight ascents and were corrected for radiation and lag errors.

Analyses were carried out with the 1000–500 mb thickness anomaly in place of the 700 mb temperature anomaly and statistics were extracted to construct Figures 5, 6 and 7. The corresponding skill scores are shown in Table V.

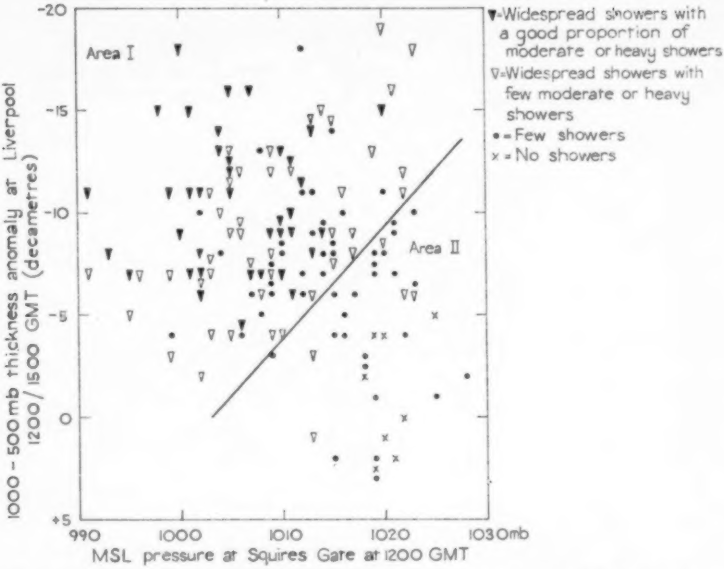

FIGURE 5—SHOWER ACTIVITY IN NORTH-WEST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

The line divides the diagram into area I containing most of the occasions of widespread showers and area II containing most of the occasions of few or no showers.

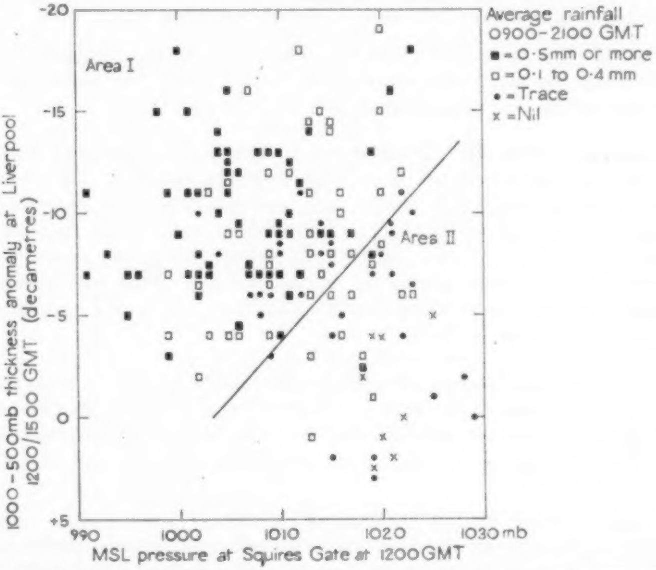

FIGURE 6—AVERAGE RAINFALL FOR SIX STATIONS IN NORTH-WEST ENGLAND FOR EACH INDIVIDUAL DAY ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

Areas I and II are the same areas as in Figure 5.

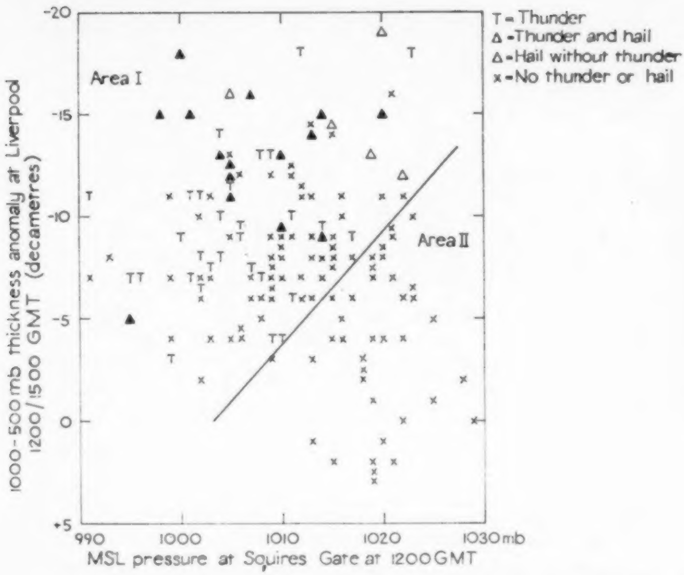

FIGURE 7—THUNDER AND HAIL IN NORTH-WEST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

Areas I and II are the same areas as in Figure 5.
Note: occasions of thunder and hail are represented by a black triangle.

An analysis was also carried out with the 1000–700 mb thickness anomaly in place of the 700 mb temperature anomaly and similar statistics extracted. The corresponding skill scores are also shown in Table V.

Association with the instability indices.—The Boyden instability index,[3] the Rackliff instability index,[4] the Jefferson instability index[5] and the modified Jefferson instability index[6] were calculated for the Liverpool 1200 GMT ascents (1500 GMT before 1957). The critical values of the indices which gave the highest skill scores in forecasting either widespread showers or few showers/no showers were obtained. A similar procedure was carried out for rainfall amount, thunder and hail. The skill scores and critical values of the indices are given in Table V.

The relative usefulness of the predictors.—Assuming that the predictors can be forecast, their relative usefulness in forecasting shower activity, rainfall amount, thunder and hail can be assessed by a comparison of skill scores. Table V shows the skill scores obtained and the critical values of the instability indices.

The highest scores for the forecasting of shower activity and the lower rainfall amounts are obtained by the 700 mb temperature predictor, the 1000–500 mb thickness predictor and the modified Jefferson instability index. The highest scores for the forecasting of the higher rainfall amounts and thunder are obtained by the two Jefferson indices and the Rackliff index. None of the predictors provide a useful indication of the likelihood of hail.

TABLE V—A COMPARISON OF SKILL SCORES

Predictors	Shower activity	Rainfall (limit 0·1 mm)	Rainfall (limit 0·5 mm)	Thunder	Hail
700 mb temperature anomaly and surface pressure	0·55	0·52	0·41	0·33	0·11
1000–500 mb thickness anomaly and surface pressure	0·53	0·51	0·33	0·27	0·11
1000–700 mb thickness anomaly and surface pressure	0·46	0·43	0·37	0·30	0·09
Boyden instability index (critical values)	0·35 (92/93)	0·44 (91/92)	0·39 (93/94)	0·46 (94/95)	0·21 (94/95)
Rackliff instability index (critical values)	0·44 (28/29)	0·45 (27/28)	0·44 (32/33)	0·59 (32/33)	0·38 (32/33)
Jefferson instability index (critical values)	0·44 (22/23)	0·49 (22/23)	0·48 (26/27)	0·66 (26/27)	0·29 (27/28)
Modified Jefferson instability index (critical values)	0·51 (20/21)	0·52 (20/21)	0·57 (25/26)	0·66 (27/28)	0·27 (27/28)

The geographical distribution of the showers.—Of the 6 stations used in the analysis, half are situated on or near the exposed windward coast, that is, Ronaldsway, Squires Gate and Valley (see Figure 8). One would expect a rather narrow coastal strip in which showers would be absent or weak on days when showers would not be initiated at sea and these stations might not be representative of north-west England as a whole. An indication of the variation of shower activity over the area was obtained by an analysis of the rainfall at each of the 6 stations.

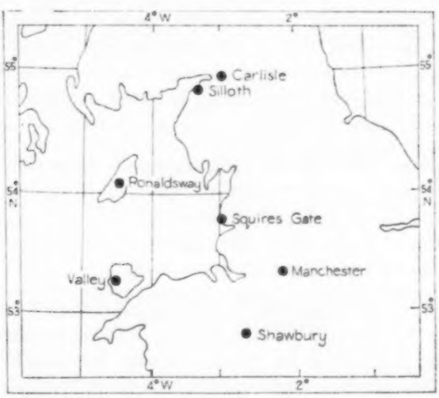

FIGURE 8—THE POSITIONS OF THE STATIONS USED

Table VI shows that the stations on or near the windward coast had the lowest average rainfall ranging from 0·4 mm at Squires Gate to 0·6 mm at Ronaldsway. The average rainfall at the other stations ranged from 0·7 mm at Silloth to 1·3 mm at Manchester. The windward coast stations also had the lowest percentage of days with a total rainfall of 0·5 mm or more, averaging

TABLE VI—RAINFALL FROM SHOWERS AT EACH INDIVIDUAL STATION (MAY TO SEPTEMBER 1953–60)

Station	Average rainfall	Percentage of days with 0·5 mm or more	Percentage of days with nil or trace
Manchester	1·3	33	51
Shawbury	0·8	30	57
Silloth	0·7	33	52
Ronaldsway	0·6	26	62
Valley	0·4	14	68
Squires Gate	0·4	15	72

18 per cent compared with 32 per cent for the other stations. The percentage of days with nil or a trace of rain averaged 67 per cent for the windward coast stations compared with 53 per cent for the other stations.

It is clear that stations on or near the windward coasts have rather less rainfall from showers than inland stations, the percentage of days with 0·5 mm or more being on average 14 per cent less at the coastal stations and the percentage of days with a trace or less about 14 per cent higher.

An analysis of rainfall from showers in south-west England[2] showed a similar effect.

A comparison with the forecasting of shower activity in south-east and south-west England.—In earlier papers [1,2] the problem of forecasting shower activity in south-east and south-west England was examined in a similar way. The best forecast skill scores obtained are all lower for south-west England than those for south-east England. The best skill scores for the forecasting of shower activity and the lower rainfall amounts are even lower for north-west England than for south-west England. It seems likely that the lower skill scores for the south-west and north-west compared with the south-east are associated with the relative proximity of the two western areas to the windward coast and the consequent motion across these areas of air which is less subjected to heating from the land. However, for the higher rainfall amounts and thunder, the best skill scores obtained for the north-west are comparable with those obtained for the south-east.

For all three areas, the highest skill scores for forecasting shower activity and the lower rainfall amounts are in general obtained by the 700 mb temperature indicator and the 1000–500 mb thickness indicator but the highest skill scores for forecasting the higher rainfall amounts and thunder are in general obtained by the instability indices.

It is interesting to note that the Boyden index, which obtains the highest skill score for the forecasting of thunder in the south-east and south-west, obtains a relatively low value for the north-west for which the Jefferson and Rackliff indices obtain quite high values. None of the predictors provide a useful indication of hail for the south-west or north-west. However, for the south-east, the Rackcliff and Jefferson indices obtain a value of about 0·5 if the freezing level is included as a further predictor.

Conclusions.—This investigation was concerned with polar airstreams from the north-west quarter affecting north-west England in summertime and was restricted to days when no fronts were situated over north-west

England. Widespread showers are likely if the associated depression is situated over Scotland or the North Sea at midday. If the depression is situated north of Scotland or over Scandinavia widespread showers are rather more likely than few or no showers. If the depression is over the Norwegian Sea, few or no showers are just as likely as widespread showers. Widespread showers with thunder are likely if a major trough or minor perturbation moves across north-west England. Widespread showers are also likely on days with uniform cyclonic isobars over north-west England, with thunder likely to occur on about one day in three. Few or no showers are likely if the isobars are anticyclonic. Places on or near the windward coasts have rather less rainfall from showers than inland stations, the percentage of days with a trace or less of precipitation being on average about 14 per cent higher at windward coast stations.

The best indication of the intensity of shower activity and the lower rainfall amounts can be obtained from (1) the 700 mb temperature anomaly at Liverpool and the surface pressure at Squires Gate, (2) 1000–500 mb thickness anomaly at Liverpool and the surface pressure at Squires Gate and (3) the modified Jefferson instability index. The best indication of the higher rainfall amounts can be obtained from the modified Jefferson index. The two Jefferson indices and the Rackliff index provide the best indication of the likelihood of thunder. None of the predictors provides a useful indication of the likelihood of hail.

The relative usefulness of the predictors has been evaluated ; which is to be preferred in forecasting depends largely on how successfully each can be forecast.

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TORNADO AT THE ROYAL HORTICULTURAL SOCIETY'S GARDEN, WISLEY

By T. W. VERNON JONES

At 1540 GMT on 21 July 1965, a tornado crossed the Royal Horticultural Society's garden at Wisley, Surrey. The tornado appears to have formed about a mile to the west of the garden in the vicinity of the River Wey. It then travelled very nearly in an easterly direction, mainly over open land as far as the Society's experimental fruit collection. It swept through the collection and went on again over open land, or land planted with very small trees, until it reached the Portsmouth Road, about half a mile away to the east.

This road is fringed with trees on both sides. About 10 trees, some of them quite large, were brought down by the tornado, and the road was blocked for an hour or so. The disturbance then travelled a short distance further, on to the nearby aerodrome where it ended its life. Some slight damage was caused on the aerodrome.

Broadly speaking the track of the tornado appears to have had a width of about 70 to 100 yards ; but in the fruit collection where the major damage was caused, the extreme width of the tornado path was more of the order of 130 to 140 yards.

The fruit trees, (mainly apples, plums and peaches), were planted symmetrically, with a space of five yards between each tree. Most of the trees were about 18 years old, and in all there were rather more than 1200 in the orchard. Of these about 140 were uprooted, and another 150 or so badly damaged. Many of the remaining trees suffered considerable root damage. It is interesting to note that the agro-meteorological station, situated just north-east of the fruit collection, was completely undamaged although within literally a few yards of uprooted or damaged trees.

For some days previous to 21 July the British Isles had been covered by a complex system of slow-moving shallow depressions. On the 21st some showers and thunderstorms had occurred. The midday upper air ascent at Crawley on the 21st is fairly typical of disturbances of this sort showing latent instability in the lower layers and convective instability around 700 millibars.

Plates II, (*a*), (*b*) and (*c*) illustrate some of the damage caused in the orchard ; and Plate II (*d*) is a picture taken close to the Portsmouth Road.

REVIEWS

Physics of the boundary layer of the atmosphere, by D. L. Laikhtman. $9\frac{3}{4}$ in $\times$ 7 in, pp. vii + 200, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1 - 5 Portpool, London, EC 1, 1964. Price : 72*s*.

This is a most interesting monograph which appeared in the original Russian form in 1961. Its availability now in English translation will provide a wider audience of micrometeorologists with a first-hand indication of the lines of thought which have evolved in their field at the Main Geophysical Observatory at Leningrad. This is one of the foremost Russian institutes publishing research in micrometeorology and, as it is one which appears to have had little communication with the 'West' in this field, the event is particularly welcome.

The monograph is expressly intended for the specialist and the classical introduction to the dynamics of atmospheric flow (Chapter 1) is kept to a minimum. Thereafter the main substance emerges quite logically in four chapters dealing with the basic properties of the vertical profiles in stationary and horizontally uniform conditions, the temporal and especially the diurnal variation in these properties, the advective transformation of the properties as a result of a sudden change in the surface conditions, and finally the variety of applications of human and economic interest (including such uncommon aspects as wind drift of ice floes and heat transfer from buildings).

The whole work carries the stamp of a thorough and sophisticated mathematical approach. For all major aspects the essential equations and solutions are set out, though frequently with greater attention to the formalities and less consideration of the physics of the problem than might be expected from the title. This is particularly evident in two of the applications which occupy the interests of micrometeorologists the world over, namely the determination of natural evaporation and estimation of the dispersion of air pollutants. Despite the foundation provided by the well-known Monin-Obukhov theory of the surface layer, there does not appear to be any realistic appraisal here of the accuracy with which vertical fluxes can be determined or estimated. In considering the diffusion from a point source the attitude is rightly taken that lateral diffusion cannot be satisfactorily treated by the K approach, but no explanation is given, nor is it made clear that by the same token vertical diffusion from an elevated source also cannot be so treated. Furthermore, although the need for a statistical approach is recognized, no indication is given of how this might be applied in practice, other than in the plainest empirical sense. It is also in the field of diffusion from sources that one is immediately struck with the apparent lack of contact with other Russian work. The more novel aspects of Monin's work in this context, well known in the 'West', receive no mention.

However the foregoing are special criticisms which are not intended to reflect on the general value of this work as a whole, and most micrometeorologists will find it informative and interesting in one feature or another. In the translated edition the symbols tend to be rather small for comfortable reading, which is a pity in view of the emphasis on the mathematical development, but otherwise the production is adequate.

F. PASQUILL

Meteorological and radiation régime of Antarctica, by N. P. Rusin. 9½ in × 7 in, pp. iv + 355, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London EC 1, 1965. Price : £6 15*s*.

This is a valuable book, the most convenient and fully up-to-date regional text on the surface meteorology and climatology of Antarctica since Meinardus' *Klimakunde der Antarktis*, published in 1938, with the addition of a neat systematic treatment in the last 160 pages of the text of what is now known of the heat balance of the surface of Antarctica. A terse style, with short sentences and brief paragraphs, makes it possible to compress a massive amount of information into a reasonably small book. The reviewer's only complaint is the absence of any index.

Since the International Geophysical Year, the only roughly equivalent works have been compendia of research papers, mostly publishing the papers read at this or that scientific meeting. The nature of such books is to illumine more or less deeply this or that aspect without attempting to cover the whole field. In these circumstances, this Russian production seems likely to become the standard reference for a decade or so — and more if it is revised at that sort of interval. There is room for similar works on the upper atmosphere over Antarctica and on other branches of geophysics. The one weakness of

this type of presentation, which points to where others may produce competitive works, is the need to set Antarctica — and preferably the sub-Antarctic zone, too, with its great ocean and the islands — into their proper context in the meteorology of the southern hemisphere, as Meinardus did to some extent in his pioneer work. This demands treatment of the whole circulation of the atmosphere in depth and of the ocean circulation likewise.

A selection of chapter and section headings will give a closer look at the actual content of the present work. The one-page "General Description" in the introductory chapters contrives to say some new things about how the gross topography of Antarctica, as it is now known, affects the atmospheric circulation ; there is some more of this in the $5\frac{1}{2}$ pages on "Conditions influencing the formation of the meteorological régime and climate of Antarctica". In the chapters on meteorology there are tables of monthly and annual mean air temperature, and maps for January, July and the year, maximum and minimum temperatures, air temperatures by wind direction, and temperatures with depth in the snow ; there are similar treatments of other elements — atmospheric pressure, wind direction and speed, cloudiness, etc. — also some attention is given to the occurrence of ice clouds and water-drop clouds and cumulus-type clouds. There are chapters on the Antarctic winter, spring, summer and autumn and a 22-page one on the local climate — including radiation balance — of the limited areas of snow-free oasis. The heat-balance section of the book has separate short chapters on direct solar radiation, diffuse radiation, total incoming short-wave radiation, reflected radiation, absorbed radiation, radiation balance, long-wave radiation leaving the surface and received from the atmosphere, leading to one on the long-wave radiation balance ; finally there are chapters on heat and moisture exchanges in the air near the surface and heat exchange within the snow itself. The essential material of these chapters is presented both in copious tables (of monthly figures) and in diagrams which are a feature of the book.

The author and Soviet meteorology are to be congratulated on achieving such a useful presentation. And there should be widespread recognition of the Israeli enterprise in making it available in English. The price is high, but not inappropriate.

H. H. LAMB

LETTER TO THE EDITOR

Photographs of frost patterns on a glass door

The photographs (Plates III and IV) were taken at 0815 GMT on 29 December 1965 at my home just over $\frac{1}{2}$ mile north-north-west of the Meteorological Office, Bracknell. The frost patterns were on the glass door between the house and the detached garage, separating the front and back gardens. Around 1000–1100 GMT in the winter the sun can shine on parts of the glass.

On the morning of 27 December both sides of the glass were covered with frost showing no structure (see left-hand side of Plate III). The sun melted a part of this frost and a few small drops of water were left on the glass. On the morning of the 28th it was found that these droplets had frozen to give the crystalline patterns shown in the photographs. The patterns persisted all day and were photographed on the following morning, using a 4 dioptre

close-up lens (hence the loss of definition on some edges). The scales shown on the photographs indicate the actual sizes of the patterns. It is interesting to note that near the top right-hand corner of Plate III can be seen the structureless frost on the back of the glass with a crystalline pattern on the near side.

The temperatures recorded in the thermometer screen at Bracknell are given below :

		Temperature at 0900 GMT	Maximum temperature	Minimum temperature
			degrees Celsius	
27th	...	−2·3	+0·8	−5·0 (at 2300 on 26th)
28th	...	−5·6	+2·0	−6·0 (at 0830)
29th	...	+0·9	+7·8	−8·7 (at 0200)

On the 29th the temperature rose steadily from the minimum of −8·7°C at 0200 GMT to about +3·5°C at 1000 and the frost melted soon after 0900.

Meteorological Office, Bracknell R. K. PILSBURY

OBITUARIES

Miss A. J. Clapham.—It is with deep regret that we heard of the death of Miss A. J. Clapham on 19 December 1965. An appreciation of her many years of service in the Meteorological Office appeared on page 58 of the February 1959 issue of the Meteorological Magazine.

Miss E. H. Geake.—It is with deep regret that we heard of the death of Miss E. H. Geake on 8 January 1966. Miss Geake retired from the Meteorological Office as a Senior Experimental Officer in March 1952 after 32 years service.

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